Measurement and Calculation of Ultraviolet Protection Factor and Solar Optical Properties

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LCAM DME TF TU Liberec

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PREPARED FOR:	**PREPARED BY:**
NAFIGATE Corporation, a.s.	Technical University of Liberec
Prosecka 64	LCAM DME TF
Prague 9	Studentská 1402/2
Identification No: 241 66 855	Identification No: 46747885
VAT No.: CZ241 66 855	VAT No.: CZ46747885
ZIP: CZ 190 00	ZIP: CZ 461 17
Czech Republic	Czech Republic
Contact: *Baturalp Yalcinkaya, Ph.D*	WWW: www.ft.tul.cz
Phone: +420 734 201 246	Phone: +420 485 353 552
e-mail: baturalp.yalcinkaya@nafigate.com	

AUTHOR:	Assoc. Prof. M. Viková, Ph.D. vice-head of LCAM	Date: 16/5/19
REVIEWED BY:	Assoc. Prof. M. Vik, Ph.D. head of LCAM	Date: 17/5/19
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1. INRODUCTION

LCAM DME TF TU Liberec was commissioned by NAFIGATE Corporation, a.s. to measure the ultraviolet protection factor (UPF), solar optical properties, i.e. solar transmittance and reflectance in the wavelength bands of 300nm to 2500nm, of a sample configuration of Nanofibrous Windows Screen. These measurements were then used to calculate parameters that relate to the solar heat transfer properties of the materials such as Shading Coefficient (SC), Solar Heat Gain Coefficient (SGHC) and Solar Heat Gain.

As per ASTM E903 - 12, the measured solar transmittance and reflectance are diffused transmittance and reflectance for normal incidence of the light beam.

All testing was conducted by the Laboratory Color and Appearance Measurement of Department of Material Engineering of Faculty of Textile Engineering at the Technical University of Liberec (LCAM DME TF TUL). All data analysis has been conducted by LCAM DME TF TUL.

2. MATERIALS UNDER TEST

Test samples marked as Sample 1 - Nanocleaner - Nanofibrous Windows Screen Nanocleaner Ultra, Sample 2 - Nanocleaner - Nanofibrous Windows Screen Nanocleaner Fresh Air, Sample 3 - Nanocleaner - Nanofibrous Windows Screen Nanocleaner Standard were supplied by NAFIGATE Corporation, a.s.

3. METHODOLOGY

The properties of the translucent samples were measured as described in the following paragraphs and the results combined using the methods described in ISO9050:2003 for spectral transmittance and reflectance for clear single glazing to give a result for the overall single skin configuration sample.

The solar optical properties of the sheets have been determined by testing for the upper and lower surface of each sheet, as a proportion of the solar radiation transmitted by the upper sheet will be reflected by the upper surface of the lower sheet.

It is important to note at this point that the combination of the test results for the upper and lower sheets of the Single Skin system was made analytically using methods prescribed in ISO 9050:2003 and has been used in this case as a “best estimate” (accurate to within ±10%, i.e. ±0.1 multiplied by the percentage value presented) of the actual values, as the Standard is written specifically for the determination of the above properties in glass. However, the standard specifically states that materials with light scattering properties (such as the material tested in this report) require much more complex analysis. Such an analysis is beyond the scope of this report.

A flat test piece was cut from the sample sheets provided by NAFIGATE Corporation, a.s.. The test piece was then placed in a Spectrophotometer SHIMADZU UV3101-PC. The absolute diffused transmittance of the sample was measured for wavelength bands of 300 nm to 2500 nm and likewise for absolute diffused reflectance using an Integrating Sphere attachment.

The solar transmittance for the solar spectrum was evaluated using the Air Mass 1 Spectrum (Figure 1). The visible solar light transmittance was calculated from the Air Mass 1 Spectrum and the daylight weighted CIE-Spectral Luminous Efficiency Curve for the Human Eye (Figure 2).

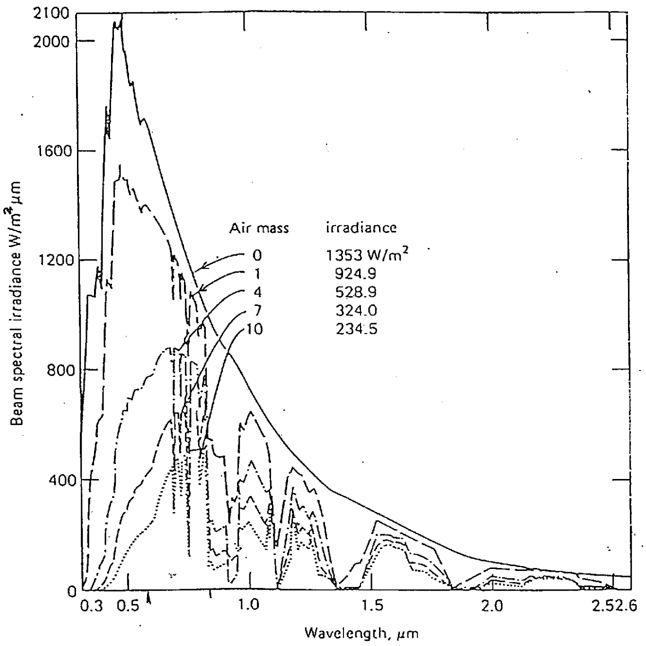


FIGURE 1: SPECTRAL DISTRIBUTION OF SOLAR BEAM FOR DIFFERENT AIR MASSES

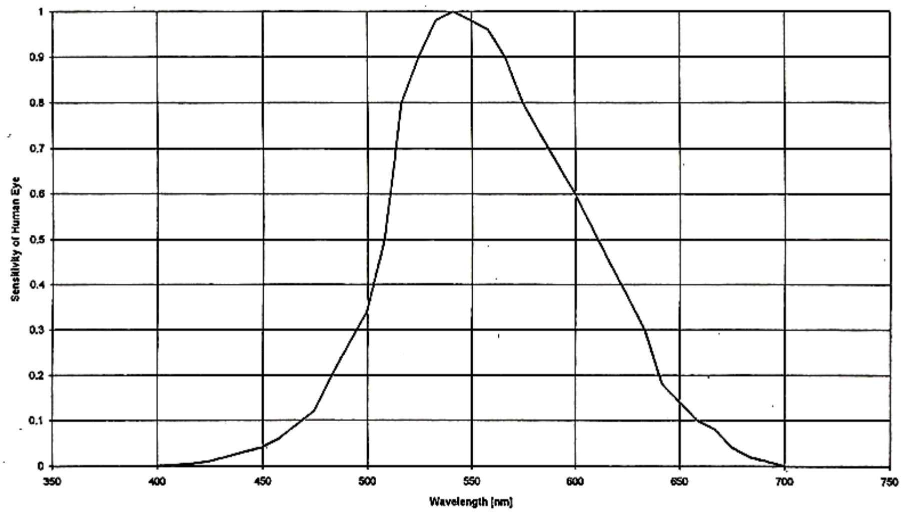


FIGURE 2: SOLAR WEIGHTED CIE-SPECTRAL LUMINOUS EFFICIENCY CURVE

The solar transmittance of the samples was calculated using the following formula in the wavelength bands of 300nm to 2500nm. The solar direct transmittance τ_e of sample shall be calculated using the following formula:

$$\tau_e = \frac{\sum_{\lambda = 300\text{ nm}}^{2\,500\text{ nm}} \tau(\lambda) S_\lambda \, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \Delta\lambda} \qquad (1)$$

where S_λ is the relative spectral distribution of the solar radiation; $\tau(\lambda)$ is the spectral transmittance of the sample; $\Delta\lambda$ is the wavelength interval.

The visible solar transmittance τ_v of the samples was obtained by using:

$$\tau_v = \frac{\sum_{\lambda = 380\text{ nm}}^{780\text{ nm}} \tau(\lambda) D_\lambda V(\lambda) \Delta\lambda}{\sum_{\lambda = 380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda} \qquad (2)$$

where D_λ is the relative spectral distribution of illuminant D65 (see ISO/CIE 10526) ; $\tau(\lambda)$ is the spectral transmittance of the sample; $V(\lambda)$ is the spectral luminous efficiency for photopic vision defining the standard observer for photometry (see ISO/CIE 10527); $\Delta\lambda$ is the wavelength interval.

The UV-transmittance of glazing is the fraction of the incident solar radiation transmitted by the glazing in the 300 nm to 380 nm range (UV-B range from 300 nm to 315 nm and UV-A range from 315 nm to 380 nm). The relative spectral distribution, S_λ used to calculate the UV-transmittance is derived from the global solar irradiance given in ISO 9845-1:1992.
The UV-transmittance τ_{UV} is calculated as follows:

$$\tau_{UV} = \frac{\sum_{\lambda = 300\text{ nm}}^{380\text{ nm}} \tau(\lambda) S_\lambda \, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{380\text{ nm}} S_\lambda \, \Delta\lambda} \qquad (3)$$

where S_λ is the relative spectral distribution of the UV-radiation; $\tau(\lambda)$ is the spectral transmittance of the sample; $\Delta\lambda$ is the wavelength interval.
This average extends over the defined UV-portion of the solar spectrum. It may not be correlated with solar radiation damage of materials and skin.

The CIE damage factor τ_{df} is calculated according to the following formulae:

$$\tau_{df} = \frac{\sum_{\lambda = 300\text{ nm}}^{600\text{ nm}} \tau(\lambda)\, C_\lambda\, S_\lambda\, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{600\text{ nm}} C_\lambda\, S_\lambda\, \Delta\lambda} \qquad (4)$$

$C_\lambda = e^{-0{,}012\,\lambda}$ (with λ in nanometres)

where S_λ is the relative spectral distribution of the solar radiation; $\tau(\lambda)$ is the spectral transmittance of the sample; $\Delta\lambda$ is the wavelength interval.

This average extends over the UV and part of the visible portions of the solar spectrum, which may contribute to the solar radiation damage of materials.

The skin damage factor F_{sd} is calculated according to the following formula:

$$F_{sd} = \frac{\sum_{\lambda = 300\text{ nm}}^{400\text{ nm}} \tau(\lambda)\, E_\lambda\, S_\lambda\, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{400\text{ nm}} E_\lambda\, S_\lambda\, \Delta\lambda} \qquad (5)$$

where S_λ is the relative spectral distribution of the solar radiation; E_λ is the CIE erythemal effectiveness spectrum; $\tau(\lambda)$ is the spectral transmittance of the sample; $\Delta\lambda$ is the wavelength interval.

The color-rendering properties of the transmitted light are given by the general color rendering index Ra. Ra shall be calculated according to the test color method which has been established by the International Commission on Illumination (CIE) as the recommended method for specifying color-rendering properties of light sources, and which also may be used for specifying modifications of daylight (see CIE 13.3).

To determine the general color-rendering index of glazing in transmittance R_a, illuminant D65 shall be used as the reference light source and the relative spectral distribution $D_\lambda\tau(\lambda)$ corresponds to the light source whose general color rendering index Ra is to be determined.

a may reach a maximum value of 100. This will be achieved for glazing whose spectral transmittance is completely constant in the visible spectral range. In the technique of illumination, general color-rendering indices R_a 90 characterize a very good and values R_a 80 a good color rendering.

Measuring the UV Protection Factor of Fabrics - Sun protection fabrics are designed to absorb or reflect the sun's UV radiation as a means of protecting the skin from damage. The rating system for fabrics specifies an Ultraviolet Protection Factor (UPF) value, which can be thought of as a time factor for the protection of Caucasian skin compared to exposure without any protection. For example, if a person would show visible erythema (sunburn) after five minutes of exposure, fabric with a UPF of fifty extends that time to five minutes times the protection factor, i.e. 250 minutes, or roughly four hours. Scientific methods

of evaluating the UPF of fabrics have been developed and specified according to Australia/New Zealand (AS/NZ) standard 4399:19961; other nations and regions have produced their own standards modeled after this original work, e.g. AATCC 183:20042 with ASTM D6544 and ASTM D6603 in the United States and EN 13758-1 in Europe.

The %Transmission results determined at each wavelength interval were used in the following formula to calculate the UPF:

$$\mathrm{UPF} = \sum_{290}^{400} E_\lambda S_\lambda \Delta\lambda \Big/ \sum_{290}^{400} \tau(\lambda) E_\lambda S_\lambda \Delta\lambda \tag{6}$$

where S_λ is the relative spectral distribution of the solar radiation; E_λ is the CIE erythemal effectiveness spectrum; $\tau(\lambda)$ is the spectral transmittance of the sample; $\Delta\lambda$ is the wavelength interval.

4. RESULTS

Solar radiation incident on a fenestration system is partly transmitted, partly reflected and the remaining is absorbed within the glazing or the coatings on their surfaces. The sum of the transmitted, reflected and absorbed portions of a glazing layer is unity:

$$\tau + \alpha + \rho = 1$$

τ is the fraction of the incident flux that is transmitted or transmittance
α is the fraction of the incident flux that is absorbed or absorptance
ρ is the fraction of the incident flux that is reflected or reflectance

Table 1 below summarizes results of the measurements of solar transmittance, reflectance and calculations of absorptance based on the equation above for Table 1

SAMPLE	Transmittance τ (%)	Reflectance ρ (%)	Absorptance α (%)	Visible Transmittance (%)
1 (Ultra)	38.9	14.7	46.3	31.7
2 (Fresh Air)	38.6	13.6	47.8	31.5
3 (Standard)	39.3	10.7	49.9	32.1

No. of Scans : 10

Table 2 Ultraviolet Protection Factor / UPF#(CSN EN 13758-1:2002)

SAMPLE	UPF	%T (UVA)	%T (UVB)
1 (Ultra)	**5.7**	*26.2*	*14.2*
2 (Fresh Air)	**6.3**	*23.2*	*13.5*
3 (Standard)	**4.6**	*27.3*	*19.4*

No. of Scans : 10

Remarks :

(1) The results given apply only to the color and weight of fabric tested. Unless otherwise stated the fabric is tested dry and relaxed.

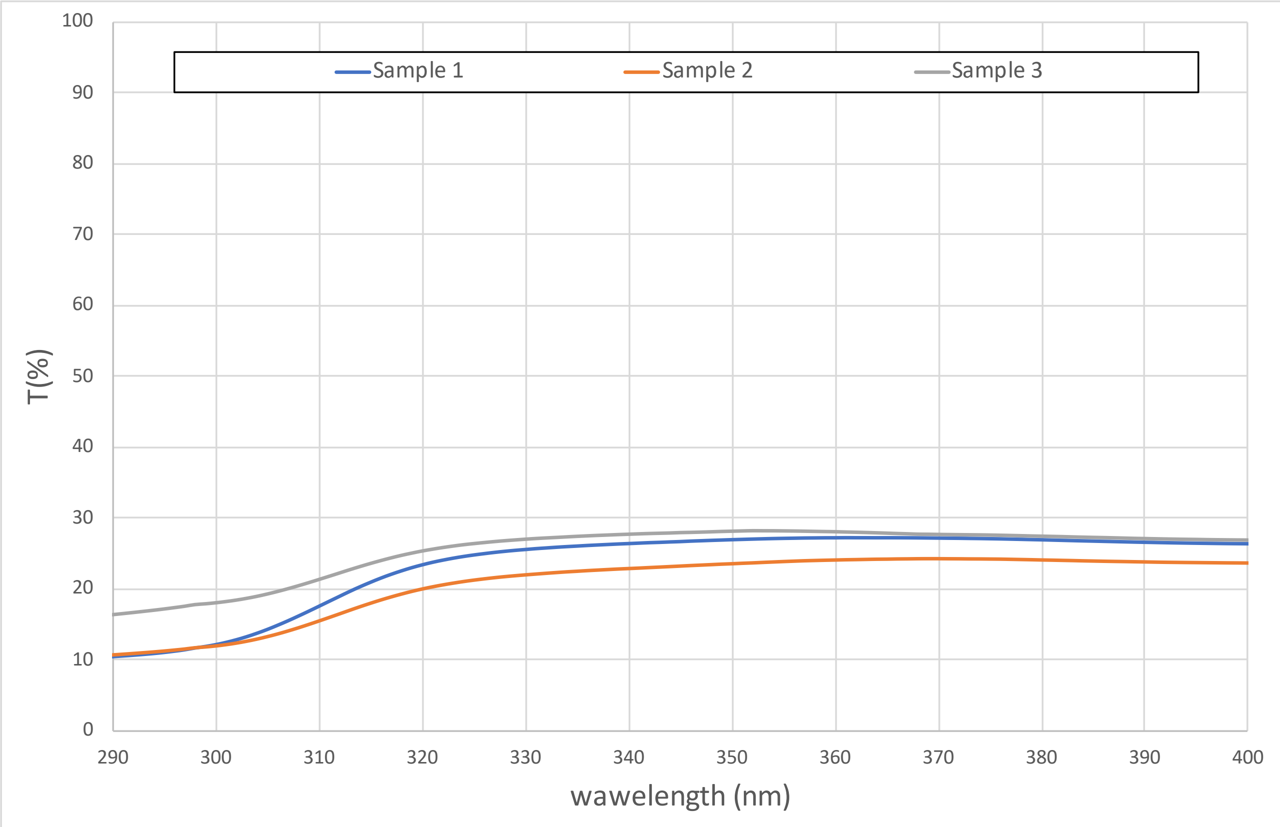
(2) This UPF Rating is for the fabric and does not address the amount of protection which is afforded by the design of the article. The manipulations involved in garment manufacture such as stretching and sewing may lower the UPF of the material.

5. RESULTS SUMMARY

Table 3 Summary of Solar Properties for the Twin Skin Test Sample

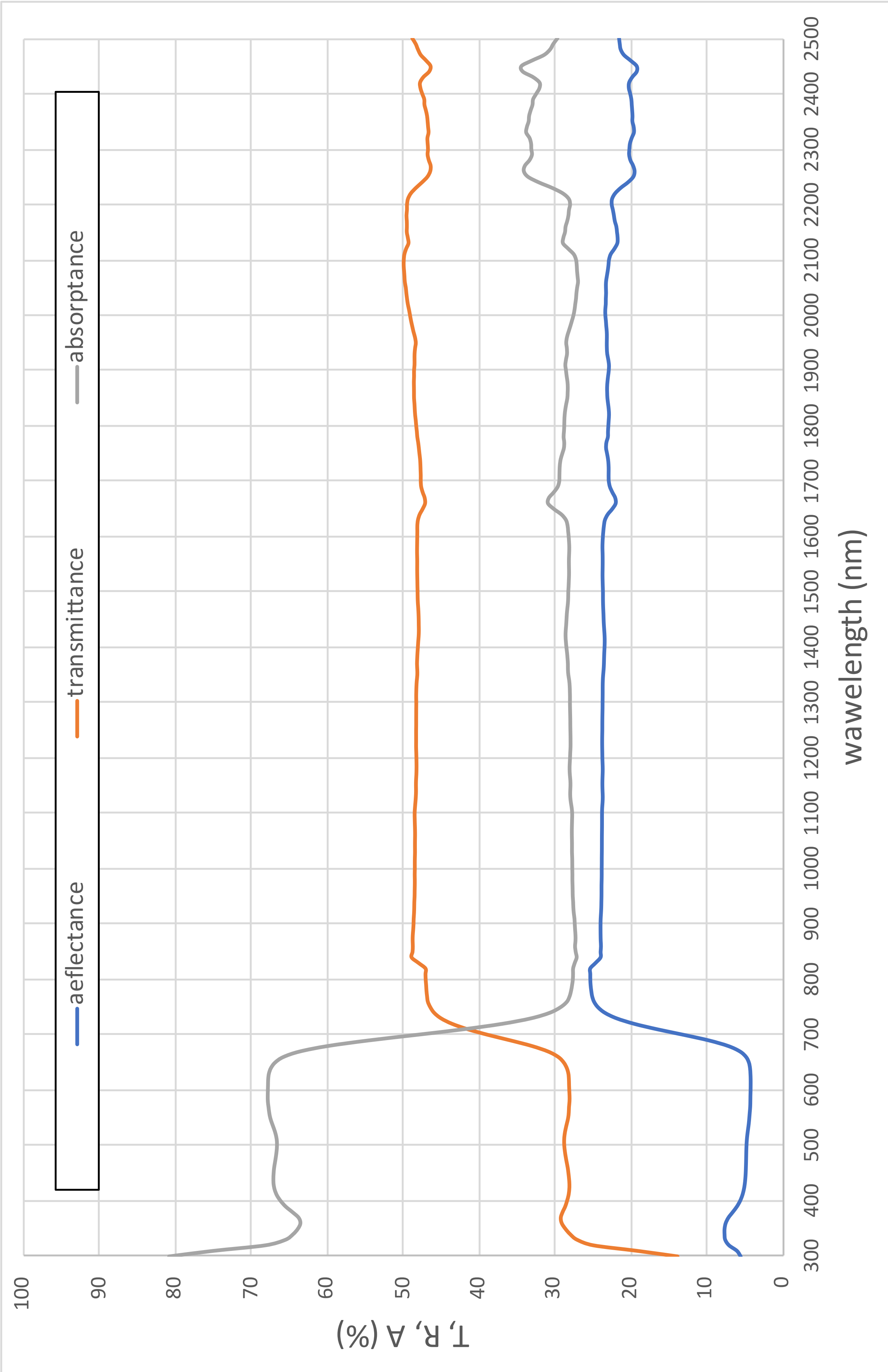
Parameter	1 (Ultra)	2 (Fresh Air)	3 (Standard)
τ_v	0.28	0.28	0.29
τ_e	0.45	0.44	0.45
τUV	0.28	0.28	0.28
τdf	0.28	0.28	0.28
Fsd	0.23	0.24	0.24
R_a	98	97	97

APPENDIX A - TEST SAMPLE SPECTRA

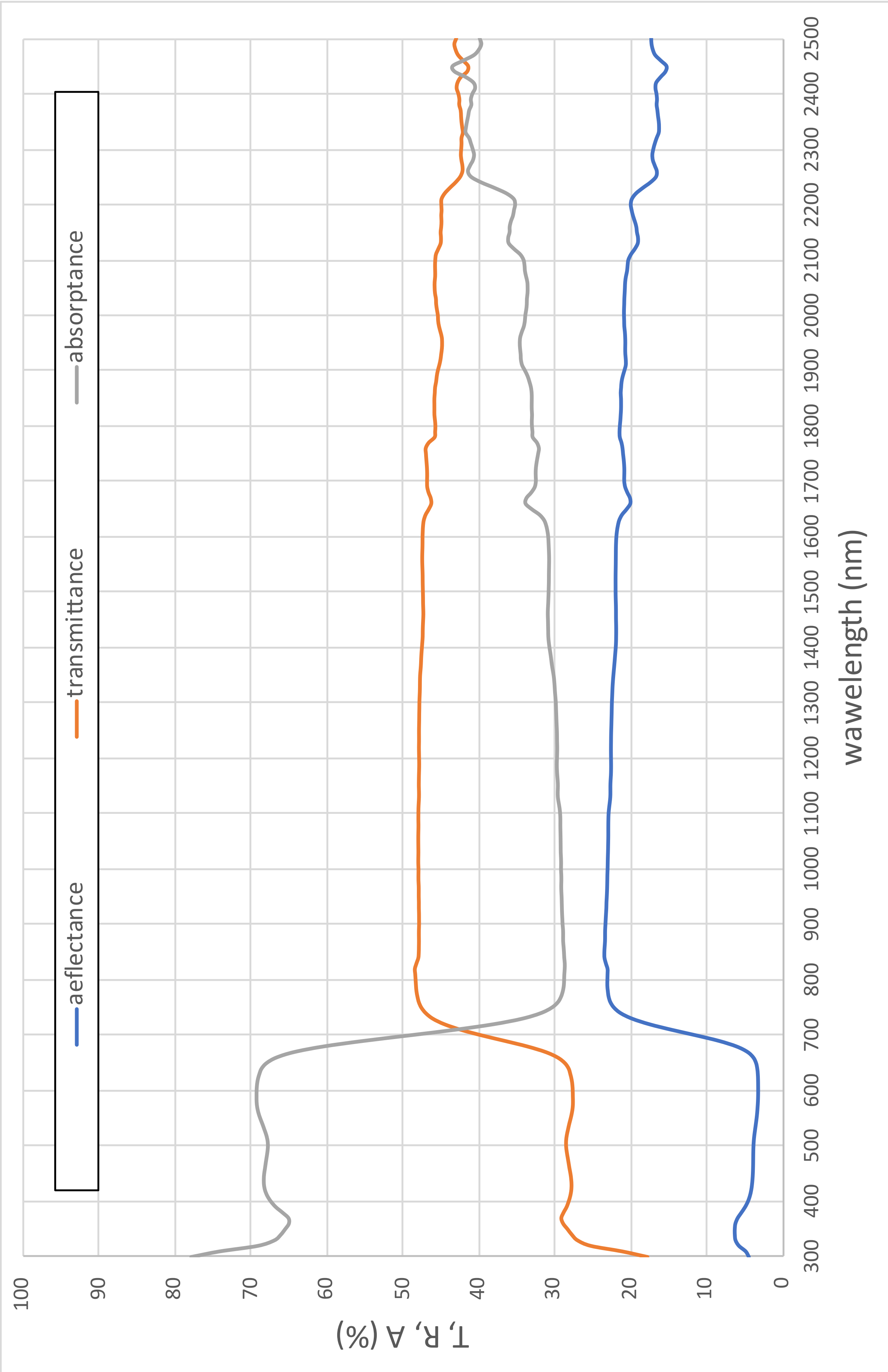


Measured sample transmittance in UPF calculation range of UV spectra

SAMPLE 1 - ULTRA



SAMPLE 2 - FRESH AIR



SAMPLE 3 - STANDARD